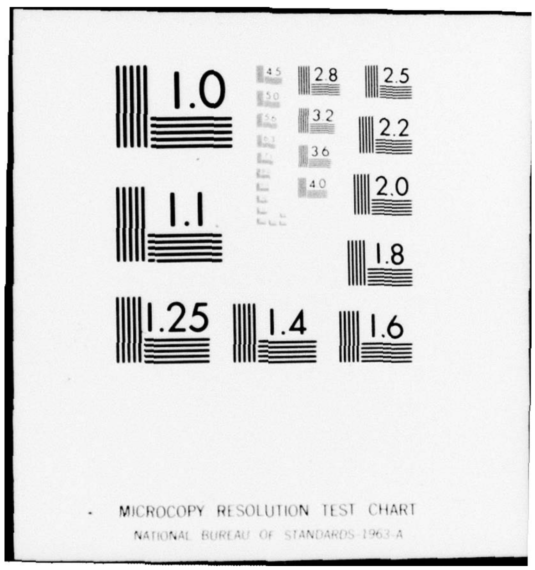
AD-A040 819   COLD REGIONS RESEARCH AND ENGINEERING LAB HANOVER N H   F/G 4/2
COMPRESSED AIR SEEDING OF SUPERCOOLED FOG.(U)
OCT 76 J R HICKS

UNCLASSIFIED   CRREL-SR-76-9   NL

1 OF 1
ADA040819

END
DATE
FILMED
7-77


1.0
1.1
1.25
1.4
1.6
1.8
2.0
2.2
2.5
2.8
3.2
3.6
4.0
4.5
5.0
MICROCOPY RESOLUTION TEST CHART
NATIONAL BUREAU OF STANDARDS-1963-A

SR 76-9

Special Report 76-9

12 NW

ADA040819

COMPRESSED AIR SEEDING OF SUPERCOOLED FOG

James R. Hicks

October 1976

CORPS OF ENGINEERS, U.S. ARMY
COLD REGIONS RESEARCH AND ENGINEERING LABORATORY
HANOVER, NEW HAMPSHIRE

COMPRESSED AIR SEEDING OF SUPERCOOLED FOG

A. Formation of Ice Crystals by Deposition Versus Formation of Ice Crystals by the Freezing of Water Droplets

B. The Influence of the Liquid Water Content of a Fog on the Efficiency of Ice Nucleating Materials

by

James R. Hicks

U.S. Army Corps of Engineers
U.S. Army Cold Regions Research and Engineering Laboratory
Hanover, New Hampshire 03755

Unclassified

SECURITY CLASSIFICATION OF THIS PAGE (When Data Entered)

REPORT DOCUMENTATION PAGE		READ INSTRUCTIONS BEFORE COMPLETING FORM
1. REPORT NUMBER (9) Special Report 76-9	2. GOVT ACCESSION NO.	3. RECIPIENT'S CATALOG NUMBER
4. TITLE (and Subtitle) (6) COMPRESSED AIR SEEDING OF SUPERCOOLED FOG.		5. TYPE OF REPORT & PERIOD COVERED (14) CRREL-SR-76-9
		6. PERFORMING ORG. REPORT NUMBER
7. AUTHOR(s) (10) James R. Hicks		8. CONTRACT OR GRANT NUMBER(s)
9. PERFORMING ORGANIZATION NAME AND ADDRESS U.S. Army Cold Regions Research and Engineering Laboratory Hanover, New Hampshire 03755		10. PROGRAM ELEMENT, PROJECT, TASK AREA & WORK UNIT NUMBERS (12) 12p.
11. CONTROLLING OFFICE NAME AND ADDRESS U.S. Army Cold Regions Research and Engineering Laboratory Hanover, NH 03755		12. REPORT DATE (11) October 1976
		13. NUMBER OF PAGES 12
14. MONITORING AGENCY NAME & ADDRESS(if different from Controlling Office)		15. SECURITY CLASS. (of this report)
		15a. DECLASSIFICATION/DOWNGRADING SCHEDULE

16. DISTRIBUTION STATEMENT (of this Report)

Approved for public release; distribution unlimited.

17. DISTRIBUTION STATEMENT (of the abstract entered in Block 20, if different from Report)

18. SUPPLEMENTARY NOTES

19. KEY WORDS (Continue on reverse side if necessary and identify by block number)

Clouds	Ice fog
Cloud seeding	Modification
Cold fog	Weather modification
Control	
Fog	

20. ABSTRACT (Continue on reverse side if necessary and identify by block number)

Two series of experiments, 25 in a light fog and 25 in a heavy fog, were conducted in the CRREL cold cloud chamber. Compressed air was used to glaciate the -4°C fog. The gage air pressure was 413.7 kPa. These tests showed that the number of ice crystals produced exceeded the number of water droplets in the fog by a factor of 21 for a light fog and 133 for a heavy fog. Approximately 2.6 times as many ice crystals were created in a heavy fog than were created in a light fog.

DD FORM 1 JAN 73 1473 EDITION OF 1 NOV 65 IS OBSOLETE 037 100 Unclassified

SECURITY CLASSIFICATION OF THIS PAGE (When Data Entered)

Compressed Air Seeding of Supercooled Fog

J. R. Hicks

INTRODUCTION

The successful dispersion of supercooled fog by artificial seeding is accomplished routinely at many airports in the United States, Europe and Russia; however, much remains to be learned of the actual physical processes involved. Two of the many questions to be answered are: 1) When supercooled fog is seeded with compressed air, do the ice crystals form directly from the water vapor in the air or do they form from the freezing of the water drops? 2) Does the amount of liquid water in a cloud or fog influence the efficiency of the seeding material?

Answers to these questions will help in establishing criteria for identifying seedable fogs and also in determining the proper type and amount of seeding material to be used to dissipate them.

EXPERIMENTAL PROCEDURES

Two series of experiments, 25 experiments in a light fog and 25 experiments in a heavy fog, were performed in the 30-m^3 cold cloud chamber at CRREL. The ambient air temperature was maintained at $-4^{o}C$ ($\pm 0.1^{o}C$). Seeding was accomplished by releasing 65.7 cm^3 of air through a 1.016-mm supersonic nozzle. The gage pressure of the air before release was 413.7 kPa, and its humidity

was maintained at saturation with respect to ice at $-4^{o}C$. The period of release was 0.1 s.

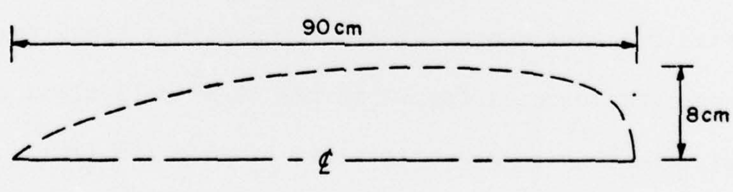
PARAMETERS MEASURED

To determine the relative importance of ice crystal formation and growth by deposition, the following parameters were measured: 1) Plume Volume, the volume of the fog within which immediate glaciation is induced by the expanding compressed air. 2) Droplet Concentration within the plume before seeding. 3) Ice Crystal Concentration within the plume after seeding.

Plume Volume

Immediately after the compressed air is released, a visible plume of glaciated fog is created. After this initial impulse, the plume expands and within 30-45 seconds the entire cloud chamber is glaciated, i.e. there are no more fog droplets.

The approximate size and shape of the (visible) plume is shown below, and its volume is calculated to be 1.02×10^4 cm^3



Concentration of Water Droplets

This parameter was obtained indirectly by measuring the liquid water content (LWC) of the fog and the mean volume radius of the fog droplets.

The liquid water content was obtained by filtering a known volume of fog through a glass wool filter and comparing its weight before and after filtering. A "light" fog contained 0.58 g m^{-3} and a "heavy" fog contained 1.66 g m^{-3} of liquid water.*

Mean volume radius was found by collecting droplets on a wet Formvar-coated microscope slide and measuring the number and size distribution of the resulting droplet replicas. A light fog contained 1.84×10^4 droplets cm^{-3} having a mean volume radius of 1.96 μm. A heavy fog contained 7.32×10^3 droplets cm^{-3} having a mean volume radius of 3.78 μm.

The following two tables, 1 and 2, show the data and calculations used to obtain these values.

---

*Lukow, T.E. and Hicks, J.R. (1974) Laboratory Studies of Cold Fog Dispersal by Compressed Air. USACRREL Research Report 327, Hanover, New Hampshire.

TABLE 1.

<u>Light Fog Analysis</u>
($LWC = 0.58\ g\ cm^{-3}$)

Droplet Radius (r) (μm)	Droplet Volume (V) ($cm^3 \times 10^{-12}$)	Droplet Number (N)	ΣDroplet Volume (V_t) ($cm^3 \times 10^{-12}$)
1	4.19	86	360.34
2	33.51	72	2412.72
3	113.10	24	2714.40
4	268.00	1	268.00

Total number of droplets (N_t) = 183

Total volume of droplets (V_t) = $5755.46 \times 10^{-12}\ cm^3$

$$\text{Mean Volume of droplets } (\overline{V}) = \frac{V_t}{N_t} = 31.45 \times 10^{-12}\ cm^3$$

Also: Mean mass of droplets $(\overline{M}) \approx 31.45 \times 10^{-12}$ g

$$\text{Mean Volume Radius } (\overline{r}_v) = \sqrt[3]{\frac{\overline{V}}{4/3\pi}} = \sqrt[3]{\frac{(31.45)\ 10^{-12} cm^3}{4/3\ \pi}}$$

$$\overline{r}_v = 1.96 \times 10^{-4}\ cm = 1.96\ \mu m$$

$$\text{Droplet Concentration (C)} = \frac{LWC}{\overline{M}}$$

$$\therefore C = \frac{0.58\ g\ m^{-3}}{31.45 \times 10^{-12} g(\text{droplet})^{-1}} \times \frac{m^3}{10^6\ cm^3}$$

$$C = 18{,}400 \text{ droplets } cm^{-3}$$

TABLE 2.

Heavy Fog Analysis

(LWC = 1.66 g m^{-3})

Droplet Radius (r) (μm)	Droplet Volume (V) ($cm^3 \times 10^{-12}$)	Droplet Number (N)	Σ Droplet Volume (V_t)
1	4.19	20	83.78
2	33.51	59	1977.11
3	113.10	80	9048.00
4	268.08	83	22250.64
5	523.60	45	23562.00
6	904.78	12	10857.00

Total number of droplets (N_t) = 299

Total volume of droplets (V_t) = 67778×10^{-12} cm^3

Mean volume of droplets ($\overline{V}$) = $\frac{V_t}{N_t} = 226.7 \times 10^{-12}\ cm^3$

Also: Mean mass of droplets ($\overline{M}$) = 226.7×10^{-12} g

$$\text{Mean Volume Radius } (\overline{r}_v) = \sqrt[3]{\frac{\overline{v}}{4/3\pi}} = \sqrt[3]{\frac{226.7 \times 10^{-12}\ cm^3}{4/3\pi}}$$

$$\overline{r}_v = 3.78 \times 10^{-4}\ cm = 3.78\ \mu m$$

$$\text{Droplet Concentration (C)} = \frac{LWC}{\overline{M}}$$

$$\therefore C = \frac{1.66\ g\ m^{-3}}{226.7 \times 10^{-12} g (droplet)^{-1}} \times \frac{m^3}{10^6 cm^3} =$$

C = 7320 droplets cm^{-3}.

Concentration of Ice Crystals

Ice crystal concentrations were determined for two conditions of each type of fog: 1) when the ice crystals were distributed evenly throughout the entire cloud chamber, $\approx$45 seconds after seeding, and 2) immediately after seeding and before the ice crystals had a chance to migrate over the entire cloud chamber. It was assumed that all the ice crystals in the cloud chamber had their initial start in the plume formed by the released compressed air.

The actual sampling of the ice crystal population was accomplished by allowing the ice crystals to settle from a height of 16.3 cm onto a microscope slide coated with a dried 3% solution of Formvar. The slide was then exposed to chloroform vapor to soften the Formvar momentarily, allowing plastic replicas of the ice crystals to form. Size, shape and number of ice crystals were then determined by observing these replicas through a phase-contrast optical microscope. Extrapolation over the entire cloud chamber volume of the number of ice crystals counted in the volume sampled yielded the total number of ice crystals formed.

The average total number of ice crystals produced in the light fog was 3.87×10^9 and the average total number of crystals produced in the heavy fog was 9.9×10^9.

Table 3 contains the test data summary from which these values were obtained.

TABLE 3.

TEST DATA SUMMARY

	LIGHT FOG			HEAVY FOG		
Test #	Xtal Diameter(D) (μm)	Total Xtals Produced(N_L) ($x10^6$)	Efficiency(E_a) Xtals/cm^3 air ($x10^7$)	Xtal Diameter(D) (μm)	Total Xtals Produced(N_H) ($x10^6$)	Efficiency(E_a) Xtals/cm^3 air ($x10^7$)
1	28	3574	5.4	38	13412	20.4
2	20	2663	4.0	48	5895	9.0
3	24	2493	3.8	40	9585	14.6
4	38	148	0.3	48	7515	11.4
5	36	1130	1.7	35	17955	27.3
6	25	713	1.1	38	12645	19.2
7	32	3002	4.6	40	9450	14.4
8	26	1843	2.8	40	9810	14.9
9	26	7246	11.0	32	16380	24.9
10	38	3051	4.6	45	12690	19.3
11	30	3559	5.4	48	10440	15.9
12	20	551	0.8	48	7335	11.2
13	24	2055	3.1	40	11115	16.9
14	28	4421	6.7	40	11430	17.4
15	26	8312	12.6	40	12645	19.2
16	30	11928	18.1	45	12420	18.9
17	32	2803	4.3	45	7740	11.8
18	34	2203	3.4	64	6435	9.8
19	50	1872	2.8	48	5175	7.9
20	28	5205	7.9	48	9630	14.7
21	26	5982	9.1	38	7245	11.0
22	34	5982	9.1	50	4680	7.1
23	34	4682	7.1	48	6795	10.3
24	32	5092	7.8	40	7650	11.6
25	32	6187	9.4	48	11295	17.2
	$\overline{D}$ =	$\overline{N}_L$ =	$\overline{E}_a$ =	$\overline{D}$ =	$\overline{N}_H$ =	$\overline{E}_a$ =
	30.1μm	3872	$5.88x10^7$	43.8μm	$9894.7x10^6$	$15.1x10^7$

RESULTS

Ice Crystal Concentration after Seeding versus Droplet Concentration before Seeding

Crystal concentration (C_X) equals the total number of ice crystals produced (N_X) divided by the volume (V_p) of the plume:

For light fog:

$$C_{XL} = \frac{N_{XL}}{V_p} = \frac{3.87 \times 10^9 \text{ Xtals}}{1.02 \times 10^4 \text{ cm}^3} = 3.79 \times 10^5 \text{ Xtals cm}^{-3}$$

$$\text{Droplet concentration } (C_{DL}) \approx 1.84 \times 10^4 \text{ droplets cm}^{-3}$$

$$\therefore \frac{C_{XL}}{C_{DL}} = \frac{3.79 \times 10^5 \text{ Xtals cm}^{-3}}{1.84 \times 10^4 \text{ droplets cm}^{-3}} = 2.06 \times 10 \text{ Xtals droplet}^{-1}.$$

which says that after seeding this light fog there were $\simeq$ 21 times as many ice crystals as there were droplets before seeding, in the same volume.

For heavy fog:

$$C_{XH} = \frac{N_{XH}}{V_p} = \frac{9.9 \times 10^9 \text{ Xtals}}{1.02 \times 10^4 \text{ cm}^3} = 9.7 \times 10^5 \text{ Xtals cm}^{-3}$$

$$\text{Droplet Concentration} = 7.32 \times 10^3 \text{ droplets cm}^{-3}$$

$$\therefore \frac{C_{XH}}{C_{DH}} = \frac{9.7 \times 10^5 \text{ Xtals cm}^{-3}}{7.3 \times 10^3 \text{ droplets cm}^{-3}} = 1.33 \times 10^2 \text{ Xtals droplet}^{-1}$$

which says that after seeding this heavy fog there were 133 times as many ice crystals as there were droplets before seeding - in the same volume.

Influence of Liquid Water Content on the Seeding Efficiency of Compressed Air

The mean ice crystal production rate for light fogs was found to be 5.88×10^7 Xtals cm^{-3} of air and for heavy fog it was 15.05×10^7 Xtals cm^{-3}; thus, for these experiments the heavy fogs produced nearly two and one-half times as many ice crystals as the light fogs did.

SUMMARY AND CONCLUSIONS

These 50 tests showed that at a temperature of $-4^\circ C$, ice crystals generated by the release of compressed air into a supercooled fog exceeded the number of droplets in the affected volume by a factor of as much as 133, indicating that the crystals are indeed generated primarily from the water vapor, by deposition, and not by the direct freezing of the fog droplets.

Also, for these tests, more ice crystals were generated in the heavy fog than in the light fog. The liquid water content of the heavy fog was $\gtrsim 2.9$ times that of the light fog. Also, the number of ice crystals generated in the heavy fog was $\gtrsim 2.6$ times that produced in the light fog. These similar ratios may have been coincidental or they may have some physical significance which could not be determined from this series of experiments.